Technique for localizing an air leak in the beamtube

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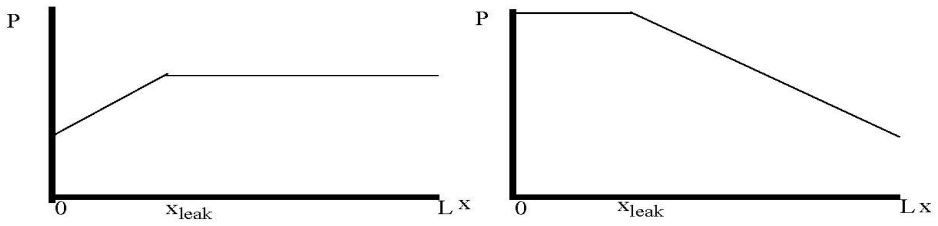
Abstract: The note describes a technique for localizing an air leak in the beamtube to a precision of 10 meters or smaller depending on the leak size. The method is a simplified version of the concept developed during the beamtube construction contract. It applies if there is one leak larger than 10^{-7} torr liters/sec in the beamtube. The concept exploits the linear relation of the flow impedence of the tube between the location of the leak and the pump ports. The measurement requires placing an RGA and a pump on the 10 inch ports at both ends of a 2km long beamtube module. The measurement consists of determining the pressure changes of nitrogen (amu 28) and argon (amu 40) when the pumps at the ends are turned on and off individually in a sequence lasting about 8 hours. The four pressure measurements permit a solution for the leak location determined by the systematic and random noise in the ion current at the mass peaks. The nitrogen and argon outgassing of the beamtube is sufficiently small that temperature variations should not affect the result. The hydrogen outgassing and its temperature variation is large enough to require an RGA since total pressure measurements would be strongly perturbed by the variation in hydrogen outgassing.

The concept and estimates



The figure shows the basic concept. A leak with magnitude, Q_{lk} torr liters/sec, occurs at a position x_{leak} meters from the origin x =0 of the tube with length L = 2000 meters. An RGA and an ion pump with pumping speed F(x) liters/sec is mounted at both x =0 and x = L. The figure on the left shows the pressure profile , P(x, F(0),F(L)), due to the leak when F(0) is on and F(L) is off. The pressure at the ends are given by

$$P(0,F(0),0) = \frac{Q_{lk}}{F(0)} \qquad P(L,F(0),0) = \frac{Q_{lk}}{F(0)} + \frac{3Q_{lk}x_{leak}}{2\pi a^3 v_{th}}$$

where a is the radius of the tube and v_{th} is the thermal velocity of the molecule. The figure on the right shows the pressure profile when F(0) is off and F(L) is on. The pressure at the ends are now given by

$$P(0,0,F(L)) = \frac{Q_{lk}}{F(L)} \qquad P(L,0,F(L)) = \frac{Q_{lk}}{F(L)} + \frac{3Q_{lk}(L - x_{leak})}{2\pi a^3 v_{th}}$$

The position of the leak is determined without detailed knowledge of the pumping speed of the pumps by using the difference in pressure at the ends for each pumping state, $\Delta P(F(0),0) = \Delta P_1 = \frac{3Q_{lk}x_{leak}}{2\pi a^3 v_{th}}$ and $\Delta P(0,F(L)) = \Delta P_2 = \frac{3Q_{lk}(L - x_{leak})}{2\pi a^3 v_{th}}$. The location of the leak is given by the ratio of the pressure differences $\frac{\Delta P_1}{\Delta P_2} = R$ as

$$\frac{x_{leak}}{L} = \frac{R}{1+R}$$

Calibration and noise. The RGA sensitivity, torr/ampere, associated with the mass numbers used in the leak localization is determined by turning off both of the pumps and measuring the ion current with time. The accumulated pressure in the beamtube will be almost the same at every location except for a small component associated with the diffusion of the gas from the leak throughout the tube. The component becomes less important with time as the total pressure increases. The diffusion time constant of the system is $\tau = \frac{3}{2av_{th}}\left(\frac{L}{\pi}\right)^2$. The diffusion time constant is 0.7 hours for molecular nitrogen and 1 hour for Argon. Reliable measurements require about 4 time constants so that a total measurement sequence including the calibration takes about 12 hours.

Sources of systematic noise in the measurement are anisotropic outgassing of gas species with contributions at amu 28 and 40. The VITON in the 44 inch and 10 inch gate valves is a source of nitrogen and argon. The total outgassing rates for CO and nitrogen (amu 28) is less than 10^{-17} torr liters/sec cm^2 and for argon (amu40) less than 10^{-19} torr liters/sec cm^2 at 23C measured at the end of the beamtube bakeout. The total gas load of CO and nitrogen is then less than 7×10^{-10} torr liters/sec and that of argon 7×10^{-12} torr liters/sec. Both contributions are small and if one assumes a 10% anisotropy become negligible in the leak localization.

Another source of systematic noise is time dependent outgassing by the RGA itself. In principle, the contribution from the RGA should not change with modulation of the pumps but may well reduce steadily in time as the RGA cleans up. The time dependent ion current will need to be removed from the data before solving for the leak location.

The systematic noise from drift of the DC amplifier in the RGA ion detection circuit can be reduced by differencing the amu 28 and 40 signals by the amu 5 signal which never is populated in RGA spectra.

Random noise sources are easier to estimate. The current noise in the electrometer used to measure the ion current is typically 10^{-14} amperes/sqrt(Hz). In the Faraday mode with 1 milliampere of electron current the sensitivity of most RGA is 10^4

torr/ampere, giving a pressure noise of 10^{-10} torr/sqrt(Hz). In an integration time of 100 seconds, the pressure fluctuation would be 10^{-11} torr. The uncertainty in the leak position becomes

$$\sigma_x = \frac{\sigma_P 2\pi a^3 v_{th}}{3Q_{lk}} = \frac{2\text{x}10^{-6}\ \text{meters}}{Q_{lk}(\text{torr liters/sec})}$$